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MEMORANDUM FOR PRS (Contractor/In-House Publication)

FROM: PROI (TI) (STINFO)

15 June 1999

SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-FY99-0144

Tim Miller, "Mixed-Mode Fracture in a Rubbery Particulate Matrix"

6th Annual International Conference on Composites
Yu/Graphs

(Public Release)



### Mixed-Mode Fracture in a Rubbery Particulate Composite

Timothy C. Miller Air Force Research Laboratory Sixth Annual International Conference on Composites Orlando, Florida June/July 1999 Engineering

20021119 130

## Outline of Presentation

- Introduction
- ► What is the problem?
- ► How do we solve the problem?
- Experimental Procedure
- ► Procedure Followed
- ▶ Difficulties Encountered
- Results
- ► Crack Initiation Toughness Results
- ► Kink Angle Results
- ► Crack Growth Results
- Conclusions and Recommendations for Future Work

Sep.



#### Problem Statement

# Reasons for Examining Mixed-Mode Cracking

■ Damage During Manufacture or Handling May Cause Cracks That Are Later Subjected to Mixed-Mode Loading

Cracks Near or at Interfaces Are Inherently Mixed-Mode Cracks

Analysis of Mixed-Mode Cracking is Substantially More Complicated Than for Mode I Cracks

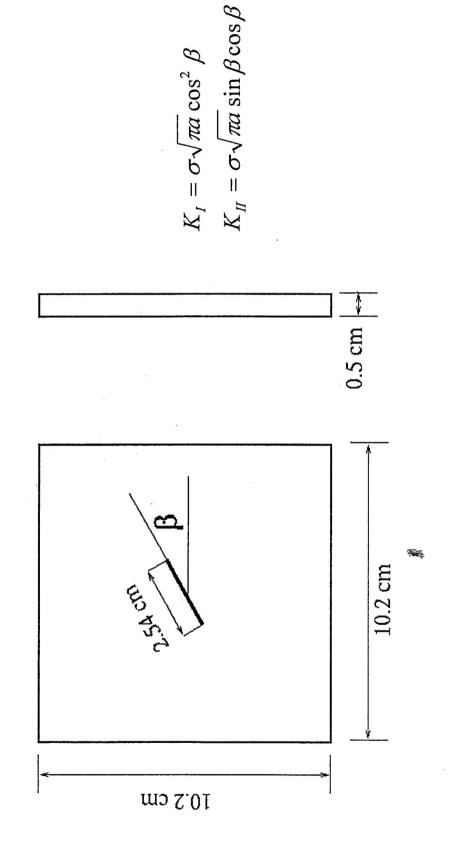


### Method of Solution

- Test Various Mixed-Mode Specimens
- ► Measure Load at Initiation
- ► Measure Crack Length (Simplified Manner) Versus Time
- ► Measure Kink Angle
- Use Finite Elements and Experimental Load Measurements to Determine Fracture Parameters at Initiation of Growth
- Use Crack Length Versus Time to Determine Simplified Crack Growth Model
- Use Kink Angle Measurements to Determine if Available Theories Can Adequately Predict Growth Direction

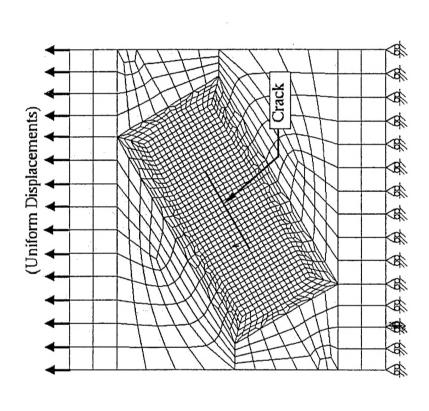
#### Specimen Geometry for Mixed-Mode Testing

Crack Angles Used Are 0 (Mode I), 15, 30, 45, and 60 Degrees



#### Sample Finite Element Mesh for Computational Models

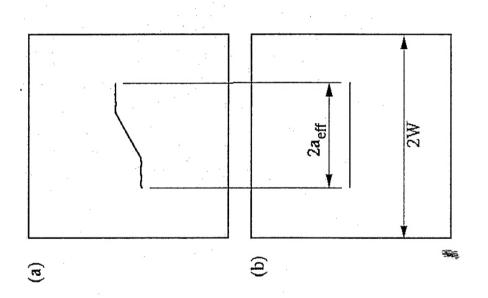
Displacement Boundary Conditions Are Used, Crack Orientation Shown Here is 30 Degrees





#### Modeling Mixed-Mode Crack Growth Using a Simplified Approach

Simplified Geometry Can Be Used to Analyze Crack Growth Rates Successfully





# Difficulties Encountered

■ Large Deformations Make In-Situ Determination of Kink Angles Difficult

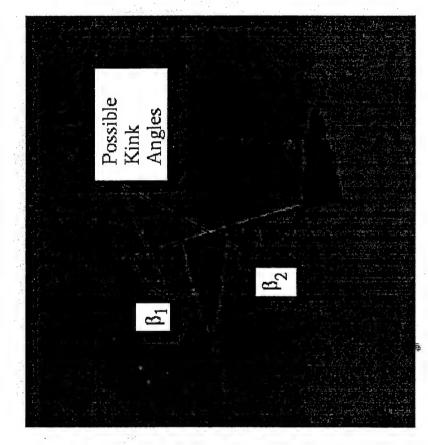
■ Mixed-Mode Inititation Toughness Locus is Linked to Micromechanisms That Are Poorly Understood

■ Linear Elasticity May Not Be Valid



### Crack in a Propellant Specimen Shortly After Initiation of Crack Growth

Large Deformations Make Kink Angle Determination Ambiguous





### Ligament Bridging Near the Crack Tip in a Rubbery Composite Specimen

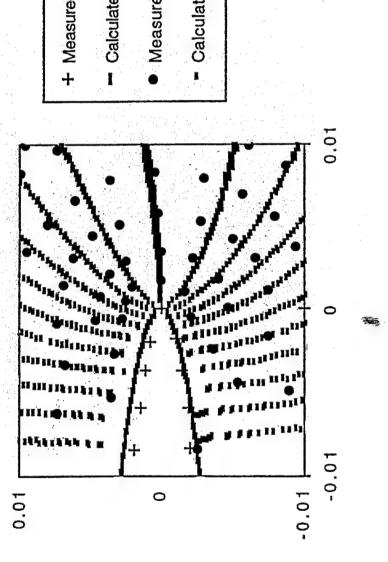
Mechanisms Such as Ligament Bridging May Account for Shape of Mixed-Mode Failure Locus in a Rubbery Particulate Composite





#### Experimental and Computed Moiré Fringes and Crack Opening Displacements for a Rubbery Particulate Composite

Good Agreement Shows That Linear Elastic Fracture Mechanics Works Well



+ Measured COD

Calculated COD

Measured Fringe Data

Calculated Fringe Data

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#### Results

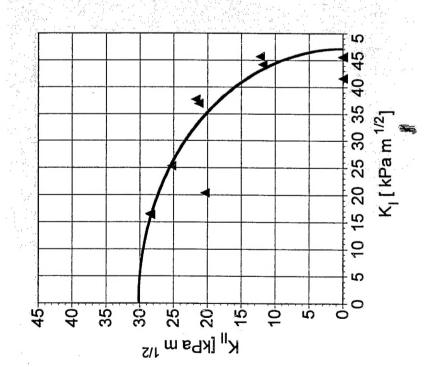
 Results for Initiation Toughness Show That Elliptical Curve Fit Works Well

■ Results for Kink Angle Determinations Show More Deviation From Theory Than Expected ■ Use of Simplified Approach to Predict Crack Growth Rate Works



#### Elliptical Failure Locus for Initiation of Crack Growth

Unlike the Failure Locus for Metals, the Mode I Fracture Toughness is Higher Than its Mode II Counterpart

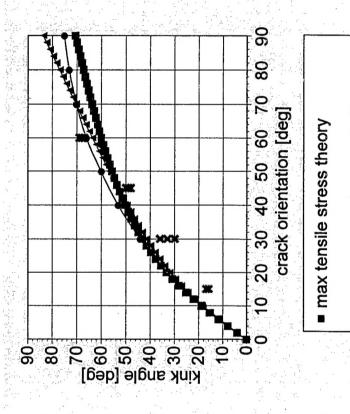


$$\left[\frac{K_{I}}{K_{IC}}\right]^{2} + \left[\frac{K_{II}}{K_{IIC}}\right]^{2} = 1$$



#### Kink Angles Plotted as a Function of Crack Orientation Angle

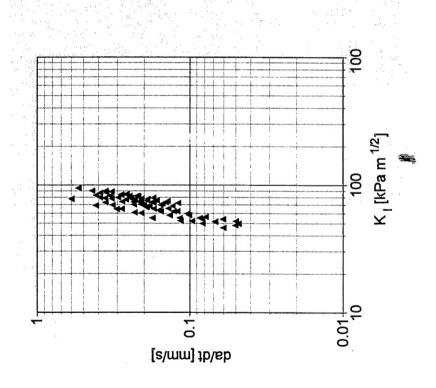
Experimental Results Show Some Deviation From Existing Theories



- max energy release rate theory
- ▲ max strain energy density theory
- \* propellant experiments

#### Mixed-Mode Experiments as a Function Effective Crack Growth Rate for the of Stress Intensity

Use of Simplified Approach Shows Agreement Even With Different Levels of Mode Mixity





#### Conclusions

:91-

- properties, high elongations, and complicated failure mechanisms, they can be studied, for a given nominal strain rate, using linear Although rubbery particulate composites have viscoelastic elastic fracture mechanics.
- The complex stress intensity factor failure locus is elliptical.
- The kink angles match available theories best at higher levels of mixity. The best theory appears to be Strain Energy Density Theory, but all of the theories made similar predictions.
- A simpified approach that uses an equivalent mode I crack can be used to predict the crack growth rate for mixed-mode cracks